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Red Queen Competitive Imitation in the UK Mobile Phone Industry

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RED QUEEN COMPETITIVE IMITATION IN THE UK MOBILE PHONE INDUSTRY

This paper uses Red Queen competition theory to examine competitive imitation. We conceptualize imitative actions by a focal firm and their rivals along two dimensions: imitation scope, which describes the extent to which a firm imitates a wide range (as opposed to a narrow range) of new product technologies introduced by rivals, and imitation speed, namely the pace at which it imitates these technologies. We argue that focal firm imitation scope and imitation speed drive performance, as well as imitation scope and speed decisions by rivals, which in turn influence the focal firm performance. We also argue that the impact of this self-reinforcing Red Queen process on firms' actions and performance is contingent on levels of product technology heterogeneity – defined as the extent to which the industry has multiple designs resulting in product variety. We test our hypotheses using imitative actions by mobile phone vendors and their sales performance in the UK from 1997 to 2008.

INTRODUCTION

> *"Once we become self-consciously aware that the possibilities of innovation within any one company are in some important ways limited, we quickly see that each organization is compelled by competition to look to imitation as one of its survival and growth strategies"* (Levitt, 1966: 38).

The emergence of what has often been referred to as the "new economy" has greatly expanded research on the power of technological innovation to create competitive dynamics that can reshape industries (Baumol, 2004; Teece, 1998). While the focus on innovation as the engine of industry evolution reflects both the potential gains that accrue to first-movers (Lieberman & Montgomery, 1988), and the dramatic impact of disruptive technologies on the competitive landscape (Christensen & Bower, 1996), it inadvertently tends to eclipse the importance of *imitation* as an agent of change. Researchers that take a broader perspective see imitation as the twin process to innovation that, arguably like innovation, also plays a role in industry evolution in all contexts (Cohen & Levinthal, 1989; Levitt, 1966; Semadeni & Anderson, 2010), but takes on even greater significance in the rapidly changing technology-intensive industries that constitute the new economy. As Baumol (2004) observes, in the new economy "no firm […] can afford to fall behind its rivals. [...] If a firm fails to adopt the latest technology – even if the technology is created by others – then its rivals can easily take the lead and make disastrous inroads into the slower firm's sales" (Baumol 2004: 246-247).

Formulating an effective imitation strategy is a problem that confronts managers in any industry (Lieberman & Asaba, 2006), but in industries with rapid technological change the problem is compounded by higher levels of uncertainty about the market performance of new product technologies (Utterback & Suarez, 1993). This "technological uncertainty" presents managers with considerable challenge when deciding how far and how fast they should imitate their rivals, and this challenge persists when their decisions, in turn, create competitive conditions that may bring further pressure to imitate (Gaba & Terlaak, 2013; Rhee, Kim, & Han, 2006). In this paper, we address the questions of how far and how fast firms should imitate their rivals, taking into account both the competitive dynamics that ensue as a result of innovation and imitation decisions, and the level of technological uncertainty in rapidly changing technology-intensive industries.

Our analysis of imitation must begin with the recognition that imitation is a strategic choice that firms pursue when they wish to lower risks and costs by learning from their rivals' actions, especially when these actions involve pioneering new technologies, or launching radically innovative products (Ethiraj & Zhu, 2008; Lee, Smith, Grimm, & Schomburg, 2000). However, imitation is also a competitive move that can pose a threat to rivals that have yet to adopt the pioneering technologies, or introduce products with similar features. When some of the laggards react to the threat by also imitating, this gives rise to "competitive imitation", a process in which imitation by some of the firms in an industry puts competitive pressure on the rest to also imitate. This process is consistent with the relationship between action and reaction that has been extensively studied by competitive dynamics research (Smith, Ferrier, & Ndofor, 2001). The main premise of competitive dynamics is that the actions of one firm, or group of firms, trigger reactions by other firms, which in turn produce a series of actions and reactions that continue as long as firms seek to improve their competitive position (Derfus, Maggitti, Grimm, & Smith, 2008; Smith, Grimm, Gannon, & Chen, 1991). In technology-intensive industries innovation triggers the competitive imitation process. Faced with mounting evidence that the innovator's new product technologies are finding a market, other firms that previously refused to match the innovator's move begin to experience increasing pressure to imitate. Their imitative move serves to entrench the new technologies in the market even further, which in turn not only increases competitive imitation but also accelerates the evolution of the industry.

The co-evolutionary process by which firms act and react to each other has been shown by organizational scholars to influence both firm performance and industry structure (Nelson & Winter, 1982). Not unexpectedly, scholars also noted that co-evolutionary processes in competitive environment have parallels with biological evolution. The parallels have led scholars to borrow from the work of evolutionary biologists, notably Van Valen's (1973) work on the co-evolution of dynamically interacting species. Of particular interest was the "Red Queen" effect: the allusion made by Van Valen (1973) to Alice's encounter with the Red Queen in Lewis Carroll's *Through the Looking-Glass* (Carroll, 1960), when he sought to explain the constant probability of species' extinction regardless of the duration of their evolutionary history.[1] Organization researchers argued that what holds for biological evolution is in principle also the case in business contexts. Thus, firms can be said to engage in a "Red Queen competition" (Barnett & Hansen, 1996; Barnett & Sorenson, 2002): the continuous and escalating activity of firms trying to maintain relative fitness in a dynamic system, such that they end up improving as fast as they can just to stand still relative to competitors.

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[1] In reference to Carroll's tale when the Red Queen responds to Alice "here, you see, it takes all the running you can do, to keep in the same place" (Carroll, 1960: 345), Van Valen noted that biological evolution features such change: species must constantly adapt in order to survive while confronting with ever-evolving rival species in an ever-changing environment.

We draw on the literature on Red Queen competition and research on competitive dynamics, imitation and technology innovation to build a model that captures how decisions to imitate new product technologies stimulate further imitation by rivals, and how this "competitive imitation" in turn influences, and is influenced by, changing industry conditions. Our study complements the competitive dynamics and imitation literature in several ways.

First, most extant research on imitation of innovations tends to see imitation as a binary variable: firms either imitate or they do not (e.g., Greve, 1998; Hsieh & Vermeulen, 2013; Makadok, 1998). In practice firms seldom imitate, or do not imitate, every aspect of their rivals' offerings, but instead tend to imitate some of the features of products introduced by rivals, while retaining existing features (Bayus & Agarwal, 2007; Giachetti & Dagnino, 2015). Two basic questions face managers in this situation when they consider imitation as the best next move: the first is how much (e.g., how many product technologies) to copy, i.e. "imitation scope" (Csaszar & Siggelkow, 2010; Narasimhan & Turut, 2013). The second is how quickly to imitate, i.e. "imitation speed" (Lee et al., 2000). In this paper we argue that the scope and speed decisions of one firm influence the scope and speed decisions of rivals. Rivals' imitation scope and speed decisions will then influence the firm's subsequent scope and speed decisions. If we step one level of analysis up to consider the entire group of industry rivals, we can see Red Queen competition in a wider perspective: the speed and scope decisions made by firms in different times induce each other's speed and scope decisions. Our contribution in this paper is to show that Red Queen competition in technology-intensive industries escalates the magnitude of imitation speed and scope choices.

Second, thus far, competitive dynamics studies have not examined how changes in the technological environment may affect the Red Queen cycle. This analysis is especially important in technology-intensive industries, where technological change, for example the emergence or decline of dominant designs, can dramatically alter competition (Chen & Turut, 2013), render obsolete a firm's capabilities (Barkema, Baum, & Mannix, 2002; Bayus & Agarwal, 2007; Utterback & Suarez, 1993), and encourage firms to develop new technology imitation strategy (Narasimhan & Turut, 2013). It is not difficult to see that changes in the technological environment that drive new product introductions are often central to the types of moves that drive Red Queen competition. For example, recent studies in the imitation and technology innovation literature (Argyres, Bigelow, & Nickerson, 2015; Giachetti & Lanzolla, 2016; Madhok, Li & Priem, 2010; Posen, Lee, & Yi, 2013) show that as industries evolve, changes in technologies and subsequently their diffusion can influence rates of imitation. Their observation complements prior work by authors such as Utterback and Suarez (1993), who point out that as the industries mature, they tend to transition from high to low levels of *product technology heterogeneity*, where low levels of product technology heterogeneity correspond to the emergence of design dominance. Low product technology heterogeneity in turn leads to low technological uncertainty: firms find it easier to know which design options are more likely to yield good market performance, and thus are more likely to imitate. Our paper examines how product technology heterogeneity moderates the Red Queen effect.

Third, existing competitive dynamics studies tend to examine antecedents and performance outcomes of action-types like pricing, marketing and capacity expansion, in industries such as professional services, professional sports, and motion pictures where technology is a minor competitive factor (Lampel & Shamsie, 2009; Ross & Sharapov, 2015; Semadeni & Anderson, 2010), or in industries such as airlines where technology is more important, but still peripheral to the main factors responsible for success (Chen & Miller, 1994; Miller & Chen, 1994; Smith et al., 1991). In contrast, we chose to examine Red Queen competitive dynamics in an industry where "creative destruction" (Schumpeter, 1942), triggered by the introduction of new products and technologies, is the primary competitive force. The mobile phone industry is a rapidly changing technology-intensive industry where continuous and swift imitation of rivals' innovation is a key prerequisite for handset vendors to maintain competitive parity. More specifically, our research site is the UK mobile phone industry from 1997 to 2008, a period during which the industry evolved rapidly, driven by incessant rivalry among a dozen handset vendors to get or keep ahead of one another.

The rest of our paper is structured as follows. We begin with an overview of Red Queen theory. We subsequently define and discuss imitation scope, imitation speed and product technology heterogeneity, and derive hypotheses about how they influence Red Queen competitive imitation. We next describe our methods and present our results. We conclude with limitations of our study, and suggestions for future research.

THEORY BACKGROUND AND HYPOTHESES

Red Queen Competitive Imitation: Focal Firm, Rivals, and Firm Performance

In this section, we develop a theory that explains the Red Queen effect in terms of a firm's imitation of new product technologies, rivals' imitation of new product technologies, and their combined impact on the firm's performance. To ensure that our theory development is consistent and clear it is important to define imitation in contrast to innovation before we move forward. As pointed out by Semadeni and Anderson (2010), in markets where firms can closely examine their competitors' product offerings and track the market performance of those offerings in real time, firms can choose between introducing to the market products with new features or copying features introduced by rivals previously. We likewise distinguish between introduction and copying, and define innovation as introducing the new features first to the market, and imitation as copying others' innovations. For the purposes of this paper, we examine imitative actions and control for innovative actions.

Two types of imitative decisions are examined: imitation scope and imitation speed. Our choice is based on evidence provided by different but complementary streams of literature.

On the one hand, the technology innovation literature has argued that a wider imitation scope is an indication that the firm's products can stay abreast of new technologies (Narasimhan & Turut, 2013). Yet, at the same time, the literature on first-mover advantage, as well as competitive dynamics literature, have focused more closely on imitation speed, arguing that higher imitation speed is a signal the firm is one of the first players committed to adopt new technologies so as to keep up with innovators and differentiate with respect to laggard rivals (Lee et al., 2000; Markides & Geroski, 2004). Though these literatures are interested in whether imitation represents a source of performance differences, they pose somewhat different research questions, and thus have progressed along independent trajectories. In practice, when a firm faces a group of rivals who are introducing new products with a variety of features at different times, they cannot focus only on scope or speed, but must consider both the question of how many of the features the firm should imitate, and also how quickly it should proceed with imitation. In this article, we propose to bring together the different analyses of imitation and competition in these bodies of literature in order to obtain a broader understanding of the roles that imitation scope and speed play in sustaining the Red Queen competitive imitation.

Because Red Queen competition describes a reciprocal back-and-forth process, firms play different roles in different time periods, and it is important to be clear and consistent about the labels we use when referring to firms. In Red Queen papers, the "focal firm" and "rivals" may switch places in the analysis over time. The "focal firm" is the industry player whose imitative moves attract attention and call for a response from other firms, the "rivals" at that specific point in time. For example, we could say that at time *t* the "focal firm", having observed new product technologies introduced by one or several of its "rivals" in *t*-1, must decide how many of these technologies it should imitate. In this context, "rivals" are all the other firms within the industry that the "focal firm" sees as competitors. "Rivals", for their part, observe the focal firm's moves, gauge the resulting performance, and decide on how many of these moves they should imitate at time *t*+1. This turns the rival firms into focal firms who are now observing and analyzing moves recently made by rivals. Their actions challenge rivals who must now consider their moves, and so on.

To summarize, the baseline Red Queen competitive imitation we develop in this section works as follows. Focal firms that successfully imitate new product technologies obtain performance advantages (e.g., sales increase) by virtue of competitive advantage that they hold vis-à-vis rivals that imitate either less intensively (i.e., lower imitation scope), or imitate more slowly (i.e., lower imitation speed). The higher performance of focal firms that imitate more intensively, or more rapidly, combined with performance losses experienced by rivals, motivate the latter to respond by increasing their imitation scope and speed. The more intense and rapid the rivals imitative response, the more the focal firm experiences a threat to its performance, and the more it feels pressure to respond, by innovating or imitating.

It is worth noting that our theory of Red Queen competitive imitation describes competition as the result of a sequence of imitative actions after a set of new product technologies are introduced. We argue that focal firms imitate innovators (i.e., technology pioneers), and rivals subsequently imitate focal firms in an incessant race to maintain competitive parity (Lieberman & Asaba, 2006). More specifically, while the rationale for the first imitations (by quickest imitators) is "informationally based", i.e. when making imitative decisions first imitators use the information generated by market performance of the new technologies introduced by innovators, the rationale for subsequent imitations is also motivated by "competitive bandwagon" pressure (Abrahamson & Rosenkopf, 1993), i.e. the pressure on non-imitators when they face diminishing profit opportunities as more of their competitors imitate innovative first movers.

The Competitive Advantage of More Active Firms: Learning and Repertoires of Actions

Taking their inspiration from Joseph Schumpeter, specifically his concept of "creative destruction" (Schumpeter, 1942) – which, concisely summarized, argues that competition is a dynamic market process in which entrepreneurs trigger change – competitive dynamics research has shown that more "active" firms, defined as firms that take more frequent competitive actions than most of their industry rivals, are more likely to attain higher performance (Ferrier Smith & Grimm, 1999; Young Smith & Grimm, 1996). In contrast, firms that lag behind most of their industry rivals when it comes to taking competitive actions tend to be at a competitive disadvantage (Miller & Chen, 1994). There are several related factors that account for this relationship. First, firms that are more active are more likely to keep pace with a rapidly changing environment (Chen, Li, & Michel, 2010; Ndofor, Sirmon, & He, 2011; Smith, Ferrier, & Ndofor, 2001). Second, because they make more moves, these firms are also more likely to change the environment in ways that are favorable to them, and less favorable to less active firms (Rindova, Ferrier, & Wiltbank, 2010). Finally, in dynamic environments in which the direction and consequences of change are uncertain, firms that are more active have a shorter *learning* cycle than firms that are less active. Active firms capture and put to use the knowledge gained from observing their rivals more quickly than firms that hesitate (Baum & Ingram, 1998; Baum, Li, & Usher, 2000; Feldman, 2000; Greve, 1996).

Learning plays a central role also in research on Red Queen competition. Initial Red Queen studies sought to show that competition and learning trigger one another in an ongoing, self-reinforcing process (Barnett & McKendrick, 2004; Barnett & Sorenson, 2002). As Barnett and Sorenson (2002: 290) put it, Red Queen is a process that results when "competition among organizations triggers internal learning processes; and learning increases the strength of competition generated by an organization". More recent Red Queen research has focused to a greater extent on learning as a process in which rivals try to figure out the causal mechanism that links a *repertoire* of competitive moves to performance (Derfus et al., 2008). The simplest competitive repertoire consists of a single move. In markets where a single move is central to performance (e.g. price competition), Red Queen is confined to single type tit-for-tat responses. In most markets, however, the focal firm's competitive advantage (disadvantage) results from a combination of successful (or failed) competitive actions[2] and firms face choices about which combination of moves they should employ. If the repertoire of possible moves focuses primarily on product technologies, firms have to assess which of the new technologies launched by rivals should be imitated, and which should be avoided.

In the remaining part of this theory section, we develop a set of hypotheses about our theory of Red Queen competitive imitation. Our argument is that focal firms that are "more active", both in terms of the number of new product technologies they imitate and the speed at which they are able to imitate, will perform better than "less active" imitators. Further, we also argue that product technology heterogeneity may constrain focal firms' learning capabilities, obstructing their ability to increase performance via imitative actions.

Scope and Average Speed of a Firm's Imitation of New Product Technologies and its Performance

How much to copy: imitation scope as a competitive response. In the specific context of new product technology in which we are interested, multiple imitation opportunities present firms with the strategic choice of how many of the technologies introduced by rivals they should imitate. This scenario is typical in technology-intensive industries, like consumer electronic industries (e.g., mobile phones and personal computers), where firms constantly face competitive threats from new product technologies that expand the set of functionalities that are offered to consumers (Bayus & Agarwal, 2007). The choice that confronts firms as new products with new functionalities enter the market is how many of these functionalities should they incorporate into their products. The choice targets what we call "imitation scope":

[2] See Chen & Miller (2012) for an extensive review comparing studies on single actions vs. action repertoires.

the extent to which a firm (in a given period) imitates a wide number (as opposed to a narrow number) of new product technologies introduced by competitors.

When looking at imitation scope we have to bear in mind that consumers evaluate the desirability of adopting new features in the context of the entire bundle of functionalities offered by the product (O'Shaughnessy, 1989). In other words, consumers compare products with, and without, a given functionality before making a purchase. The inclusion of a functionality will not necessarily motivate them to make a purchase, unless the additional functionality adds to the value of the package as a whole. First movers (i.e., innovators) must make this evaluation without prior market data (or at best consumer research data), while imitators can use the market performance of new functionalities when making this decision (Carpenter & Nakamoto, 1989). The problem, however, is that firms have data on multiple functionalities, some of these functionalities are present in the same product, which makes it hard to evaluate them separately, while others are spread across different products in a variety of combinations – presenting another evaluation challenge (Krishnan & Bhattacharya, 2002).

If firms cannot analyze the sales potential of individual functionalities, the question that arises is whether they can evaluate the potential of sets of functionalities. Technology innovation literature that examines the consumer buying behavior of products with multiple functionalities (Chen & Turut, 2013) suggests that when firms have to assess how consumers evaluate a set of objects – in our case products that offer certain functionalities – they will evaluate the options they are presented by considering both the absolute utility of each feature (e.g. text messaging in mobile phones), and their relative standing in the choice set (i.e., how valuable is text messaging relative to other functionalities in the set). The evaluation relies on reference points that are endogenous to the choice set (Baucells, Weber, & Welfens, 2011). This can be the product that the consumer currently owns, or some idealized combination of functionalities in the product that the consumer wishes to purchase (Zhou, 2011). Reference points in a technologically mature industry where products perform a stable set of well established functionalities are more likely to be based on price, since the difference between the functionalities of old and new products is not substantial. However, in industries where technology is evolving rapidly, as in most technology-intensive industries, consumers' reference points are future oriented, and tend to change as new functionalities are introduced. As Chen and Turut (2013: 2748) put it: "Context dependent preferences are especially relevant for consumers' adoption of technology innovation because the reference points of product attributes in consumers' minds are likely to evolve over time with the advance of technology and the arrival of new products in the market; this influences consumers' adoption of products with new technology and consequently firms' innovation strategies." Introduction of new functionalities in the form of new product features or attributes tends to shift the reference point towards the innovative feature, and away from old features. Put differently, consumers will value the entire set of functionalities in a product more if the product includes new functionalities that represent the next step in the evolution of underlying technologies. This shift in reference point as technology evolves strongly influences the competitive logic in these markets. While it creates incentives to innovate new functionalities, it creates even stronger incentives to imitate (Narasimhan & Turut, 2013).

Narasimhan and Turut (2013) provide empirical support for the advantages of imitation, showing that firms attain higher performance if they choose to imitate as many pioneering features introduced by rivals as possible, rather than differentiate by introducing their own features. Their conclusions are in line with other empirical studies of consumer attitudes that suggest that consumers display a strong bias against brands that lack the latest technologies in markets where technology is rapidly evolving, and at the same time evaluate more favorably brands with a reputation for staying abreast of new technologies (O'Shaughnessy, 1989; Pessemier, 1978). From the point of view of firms that are considering how many of the new functionalities they should adopt in the new product offerings, this suggests that firms are more likely to gain sales if they adopt as many of the new features as their capabilities will allow. This leads to the following hypothesis:

Hypothesis 1a. An increase in the focal firm scope of imitation of new product technologies will positively influence its performance.

How fast to copy: average speed of imitation as a competitive response. Another question firms must confront is how quickly to imitate rivals' moves (Markides & Geroski, 2004). Similar to our discussion on imitation scope in technology-intensive industries where firms launch products that combine multiple technologies, and hence present multiple imitation opportunities, a related decision that confronts firms is how quickly these multiple technologies should be imitated. At the product line level, this choice targets what we call "average speed of imitation": the average time it takes for the focal firm to adopt the set of new product technologies introduced by rivals.

From a decision-making perspective, the question of how quickly a firm should imitate its rivals has been explored primarily from the perspective of first mover advantage (Lieberman & Montgomery, 1988). The merit of moving first with a new product has been extensively argued and documented (Makadok, 1998). Researchers, however, have also come to recognize that the firms that move later can avoid many of the risks that confront first movers by observing, analyzing, and then imitating their products and technologies (Lieberman & Montgomery, 1998; Markides & Geroski, 2004). What is less certain is how quickly late movers have to act if they want to minimize risks and maximize the advantages of early information. Studies in the competitive dynamics and first mover literature suggest that on the whole, fast imitators, i.e. firms that imitate earlier than others pioneering innovations, will generally do better than firms that are slow to imitate (Lee et al., 2000). The advantages of fast imitation are especially strong in industries where first adopters of new product technologies benefit from "spatial preemption," the filling of product differentiation niches before late adopters enter (Rao & Rutenberg, 1979; Rindova, Ferrier, & Wiltbank, 2010). Because spatial preemption limits the product differentiation opportunities available for late adopters, we expect rapid imitation of new product technologies to deliver higher performance for imitators that move faster. In other words, higher average speed of imitation of new product technologies offers the focal firm more differentiation opportunities with respect to later imitators, and is likely thereafter to lead to higher sales volume.

The advantages of quick imitation of new product technologies, however, are not confined to spatial preemption. It also has significant impact on consumer perception of firm reputation. Research shows that consumers tend to view firms that quickly adopt new technologies as generally more innovative (Alpert & Kamins, 1995; Carpenter & Nakamoto, 1989; Kardes & Kalyanaram, 1992). This judgment creates a "halo" effect that favorably skews the evaluation of the firm's product line, and hence contributes to sales growth. In contrast, the product lines of firms that are slow to adopt new technologies (i.e., have low average speed of imitation) are judged more negatively by consumers. This negatively skewed judgment tends to depress sales growth for slow adopters. Therefore, in a context of multiple imitation opportunities, firms with high average speed of imitation of new product technologies will be viewed as technology leaders and hence will benefit from a higher reputation among customers that will positively enhance their sales performance. Thus, we predict:

Hypothesis 1b. An increase in the focal firm average speed of imitation of new product technologies will positively influence its performance.

Scope and Average Speed of a Firm's Imitation of new Product Technologies and the Scope and Average Speed of Rivals' Imitative Actions

As noted earlier, Red Queen competition suggests that as the number of focal firm actions increases, the number of rival firm actions increases as well (Derfus et al., 2008). That is because the greater the focal firm's competitive activity, the more competitors are likely to perceive a threat to their performance, which in turn makes it more likely that they will respond (Barnett & Hansen, 1996; Barnett & McKendrick, 2004). In other words, a focal firm's increase in competitive activity will present rivals with a challenge that will increase in magnitude if the focal firm moves further ahead in terms of new product offerings, leaving rivals with market spaces that are less and less valued by customers. This will force rivals to respond with competitive moves of their own in order to close the gap and maintain their position.

Lieberman and Asaba (2006: 380) note that, "rivalry-based imitation often proceeds over many rounds, where firms repeatedly match each other's moves". Generally speaking, rivalry encourages imitation, which in turn encourages more rivalry. As Competitive dynamics literature suggests that to maintain competitive parity competitors must imitate intensively (i.e., imitation scope) and rapidly (i.e., imitation speed). This imitation effort escalates as rivals struggle for profits and market share. Indeed, the improved focal firm performance derived from intense and rapid imitation of new product technologies comes at the expense of rivals' performance, which, in turn, may prompt rivals to trigger aggressive imitative actions that emulate the focal firm's successful imitations. This gives us the following hypotheses:

Hypothesis 2a. As the scope of the focal firm's imitation of new product technologies increases, the scope of rivals' imitation of new product technologies will also increase.

Hypothesis 2b. As the average speed of the focal firm's imitation of new product technologies increases, the average speed of rivals' imitation of new product technologies will also increase.

Scope and Average Speed of Rivals' Imitation of New Product Technologies and the Focal Firm Performance

Various studies in the management and strategy literature have analyzed if and how the intensity of competitive rivalry affects industry members' performance. A study by Young et al. (1996) shows that increases in the number of rival actions in a sample of software firms has a detrimental effect on the focal firm performance. Similarly, Chen and Miller (1994) and Smith et al. (1991) analyses of competitive dynamics in the airline industry show that when rivals respond more strongly to earlier moves by the focal firm, performance of the latter will decrease. They suggest that the more actions rivals carry out, and the greater the speed of execution, the more the focal firm performance will be damaged.

Likewise, in their analysis of Red Queen competition, Derfus et al. (2008) show that when the focal firm undertakes a new competitive action, the number of rival countermoves and the speed of rival countermoves increase, leading to a decrease in focal firm performance. Overall, extant studies point to broader and faster imitation by rivals as having a negative impact on focal firm performance. This gives us the following hypotheses:

Hypothesis 3a. With the scope of the focal firm's imitation of new product technologies held constant, as the scope of rivals' imitation of new product technologies increases, focal firm performance decreases.

Hypothesis 3b. With the average speed of the focal firm's imitation of new product technologies held constant, as the average speed of rivals' imitation of new product technologies increases, focal firm performance decreases.

The Moderating Effect of Product Technology Heterogeneity in the Market

Recent studies in the strategy and technology innovation literature (Argyres, Bigelow & Nickerson, 2015; Giachetti & Lanzolla, 2016; Madhok et al., 2010; Posen et al., 2013) suggest that evolving industry characteristics, in particular changes that are caused by the introduction of new technologies, can affect the level of uncertainty in the competitive environment. This in turn constrains the firms' ability to learn from rivals, reducing effectiveness of imitation as a competitive weapon. These findings are in line with previous work on the industry life cycle (e.g., Utterback & Suarez, 1993), that points out that as industries mature they tend to transition from high to low levels of *product technology heterogeneity* – where high levels of product technology heterogeneity correspond to a situation in which there are more designs contending for consumer attention, and more product features that can be incorporated into products. In other words, the level of product technology heterogeneity expresses the extent to which products launched by all competitors are equipped with similar or different technologies. A low level of product technology heterogeneity is the result of "high degree of design dominance", while a high level of product technology heterogeneity is the product of "low degree of design dominance".

Since high product technology heterogeneity is a situation where a clear dominant design has yet to emerge, often because several key technologies vie for acceptance, firms in such an environment have to cope with technological uncertainty when it comes to deciding which technologies they should install in their products (Lippman & Rumelt, 1982; Makadok, 1998; Utterback & Suarez, 1993). One way for firms to deal with technological uncertainty is to observe the technologies imitated by rivals previously. But the information obtained from observing rivals' imitation when technological uncertainty is high is more noisy, and hence less reliable guide for judging the merits of new product technologies (Posen & Levinthal, 2012). In rapidly changing competitive environments, as is the case in Red Queen competition, technological uncertainty can therefore slow down the learning process, constrain decision-making and hence adversely affect performance. As Barkema et al. (2002:

921) point out: “organizations that learn slowly from competitors may find their innovation performance rapidly deteriorating”.[3]

This leads us to argue that the extent to which a focal firm and rivals’ imitative actions affect the focal firm’s performance (Hypotheses 4a/b and 6a/b), and the extent to which the focal firm’s imitative actions trigger rivals’ imitative actions (Hypothesis 5a/b), depends on the *level of product technology heterogeneity*.

Product technology heterogeneity: focal firm’s scope and average speed of imitation and focal firm performance. As we noted earlier, *high product technology heterogeneity* increases imitative uncertainty. This means that focal firms are less certain which product technologies they should imitate, and which they should ignore. And it also means that the learning process for focal firms is more difficult, since in this uncertain scenario firms need time and resources to figure out which are the most effective technology adoption strategies. Thus, although, in general, we expect focal firms that are particularly “active” when imitating new product technologies (i.e., high imitation scope and speed) to stand a better chance of successfully differentiating their offerings when compared to imitating rivals that are less active, this prediction may not hold when product technology heterogeneity is high. When product heterogeneity is high firms that adopt many new product technologies (i.e., high imitation scope), and do so more quickly than their rivals (i.e., high imitation speed) also run the risk of betting against the design that will subsequently gain market acceptance (i.e. the dominant design). Betting against the dominant design is likely to adversely affect the performance of focal firms (Argyres, Bigelow, & Nickerson, 2015; Utterback & Suarez, 1993). In contrast, low product technology heterogeneity (i.e., high design dominance) reduces imitation risks largely because it is easier to evaluate the merits of new product

[3] As also remarked by Posen and Levinthal (2012) in their analysis of turbulent (i.e., rapidly-changing) environments, “turbulence reduces the value of efforts to generate new knowledge because the lifespan of returns to new knowledge is reduced in a world in which change is more frequent” (Posen & Levinthal, 2012: 594).

technologies sufficiently early to avoid making the wrong design decisions. We thus posit that:

Hypothesis 4a. Product technology heterogeneity negatively moderates the relationship between the focal firm scope of imitation of new product technologies and its performance.

Hypothesis 4b. Product technology heterogeneity negatively moderates the relationship between the focal firm average speed of imitation of new product technologies and its performance.

Product technology heterogeneity: focal firm's scope and average speed of imitation and rivals' imitation response. Various studies on organizational learning have examined how rival firms use imitation when the performance outcomes of this strategy are uncertain. For example, Rhee, Kim and Han (2006: 504) point out that "decision makers confronting conflicting mimetic requirements and practices find it difficult to make an imitation decision because conformity to one undermines the isomorphic support of other elements". Likewise, Cameron (2005) shows that decision makers who face conflicting external information reduce the attention paid to such data when updating their private information, and are then likely to take strategic decisions that deviate from industry norms. In essence, evidence suggests that obstacles to processing observed information—caused by heterogeneous information—reduce imitation (Gaba & Terlaak, 2013).

When *product technology heterogeneity is high* rivals confront markets in which many product configurations compete. Under these conditions it is unclear which of these configurations will prevail and which will fail. Nor can rivals assume that the entire set of actions by the first imitators conveys information that is necessarily reliable and useful for their imitation decisions. Their best course of actions is to keep their strategic options more open, and imitate with greater caution, both in terms of scope and speed. The aim of rivals at this point is to reduce the risk of betting too early on product features that may not become part of the future dominant design. This means that rivals, having observed the focal firm's imitative actions, will imitate a limited number of technologies, and do so at lower speed. At the industry level, this behavior leads to reduced probability of overreaction to new product technologies that are introduced by earlier movers.

Generally speaking, therefore, the technological uncertainty triggered by high product technology heterogeneity mitigates the pressure for imitative bandwagons (Abrahanson & Rosenkopf, 1993).[4] In contrast, when there is *low product technology heterogeneity*, i.e. high degree of design dominance, and therefore there is lower technological uncertainty because of the fewer product configurations in the market, rivals can infer more accurately the moves that focal firms are likely to make, and hence calculate with greater certainty the consequences of their moves. This in turn encourages rivals to pursue imitative actions more aggressively (i.e., higher imitation scope and speed). This gives us the following hypotheses.

Hypothesis 5a. Product technology heterogeneity negatively moderates the relationship between the scope of the focal firm's imitation of new product technologies and the rivals' scope of imitation of new product technologies.

Hypothesis 5b. Product technology heterogeneity negatively moderates the relationship between the average speed of the focal firm's imitation of new product technologies and the rivals' average speed of imitation of new product technologies.

Product technology heterogeneity: rivals' scope and average speed of imitation and focal firm performance. When deriving Hypothesis 5, we argued that high product technology heterogeneity reduces rivals' propensity to respond to the focal firm with imitation. This is because, given the high technological uncertainty, rivals are likely to keep their options more open, and follow focal firm's actions only if they prove to be successful. In

[4] In a similar vein, LiCalzi and Marchiori (2013) argue that in a dynamic environment it is more effective to focus on a relatively narrow set of strategic actions in order to track and adapt to environmental shocks accurately.

fact, by imitating first the focal firm runs the risk of betting on the wrong dominant design (Hypothesis 4), whereas rivals, by imitating later, avoid wasting resources by imitating only those new technologies (previously adopted by the focal firm) that have demonstrated greater acceptance by consumers. We can regard these rival firms as "second mover" imitators that derive their advantage from the technological uncertainty of the market (Lieberman & Montgomery, 1998). To put this in perspective, rivals' imitative decisions of new product technologies (in terms of scope and speed) will benefit from high technological uncertainty at the expense of the focal firm's performance because they are able to adjust their actions after observing the focal firm's earlier moves. This leads to the following hypotheses:

Hypothesis 6a. Product technology heterogeneity negatively moderates the relationship between the scope of the rivals' imitation of new product technologies and focal firm performance.

Hypothesis 6b. Product technology heterogeneity negatively moderates the relationship between the average speed of the rivals' imitation of new product technologies and focal firm performance.

Figure 1 depicts our research model, showing the hypothesized relationships as described above.

Please insert Figure 1 around here

METHOD

Sample and Setting

We test the proposed hypotheses in the specific context of the UK mobile phone industry. Our sample includes handset vendors that operate in the UK mobile phone industry from 1997 to 2008. During this period, 48 new product technologies were installed in 566 new mobile phones introduced and sold by the following firms: Nokia, Motorola, Samsung, LG, Ericsson, Sony, Sony-Ericsson, Siemens, Philips, Panasonic, Sagem, NEC, Alcatel. These firms constitute almost the entire UK mobile handset industry. Mobile phones can be distinguished in two categories: (a) “regular phones”, or “feature phones”, offering mainly basic phone and multimedia functionalities, and (b) “smartphones”, namely handsets equipped with advanced operating systems offering PC-like capabilities, more expensive than regular phones and targeted at the high-end market. Smartphones constitute most of the UK market today, but were a small niche during the period under study. To maintain consistency, we decided to exclude smartphone devices from our sample. Information about product innovations introduced by the 13 mobile phone vendors in the UK market were collected from the specialist industry magazines *What Mobile*, *What CellPhone* and *Total Mobile.* We selected only product technologies that were explicitly reviewed by these magazines over our study period.

We believe that there are several reasons why the UK mobile phone industry over the 1997-2008 time period is a particularly suitable setting to test our hypotheses about Red Queen competitive imitation. First, the mobile phone industry, especially in developed countries like the UK, has often been described as a fast changing environment characterized by rapid new product technology introduction and quick technological obsolescence (Mintel International Group Limited, 1997–2008), all theoretical factors that underline the pressure that leads firms to aggressively adopt new technologies in order to remain competitive.

Second, our observation period covers various stages of the industry’s evolution. From the mid-90s to the end of the 2000s, the mobile phone diffusion rate (i.e., the number of handsets per 100 habitants) grew from about 10% to a saturation level (over 100%), with the growth rate of diffusion particularly high during the second half of the 1990s, and gradually diminishing over the 2000s.[5] Moreover, the progressive transition of handsets in the UK from niche to mass-market products encouraged competitors to launch their most advanced models and technologies in the market, making the competitive environment particularly challenging. These factors indicate that over the analyzed twelve-year period the industry passed from the growth to the maturity stage of its life cycle. Because our data covers both growth and maturity, we are able to examine changes in the competitive interactions and learning processes that may occur as the technology environment evolves over time (Baum et al., 2000). This is in line with Derfus et al. (2008) recommendation that research on Red Queen effects should study empirical settings covering both early and late stages of the industry evolution.

Third, mobile phone vendors in our sample are very large firms that extensively advertise their product innovations in a wide variety of media and marketing channels. This means competitive actions related to product innovations are highly visible – an important condition to assume imitative actions in the UK mobile phone industry are taken deliberately.

Fourth, the information we gathered from several secondary sources indicated that, at least at the European level, new product technologies in the mobile phone industry were introduced more or less the same year across all European countries.[6] This makes the UK a representative sample of the European market.

Fifth, smartphone devices were a small market category prior to the introduction of Apple's iPhone and its operating system iOS in mid-2007, and the launch of Google's Android operating system in 2008. The introduction of these product innovations triggered the rapid market decline of mobile phones that did not use advanced operating systems. To

[5] Data about mobile phone diffusion in the UK market were collected from Ofcom, the UK telecom regulatory body.

[6] The secondary sources from which we gathered information about the timing of new product technologies introduction were: (a) the FACTIVA database, which searches thousands media sources at the worldwide level; (b) the mobile phone vendors' annual reports and newsletters; (c) various online catalogues for handsets, like the GSMArena website (http://www.gsmarena.com); (d) books, newspapers, press releases, and business publications.

ensure consistency in our analysis, we decided to consider only mobile phone technologies introduced before 2008.

New Product Technologies, Technological Systems and Imitation

Our study focuses on drivers and performance outcomes of new product technology imitations by UK mobile phone companies. We define a product technology as any hardware or software allowing the handset to perform a certain function. We assume a “new product technology imitation” occurs after a new product technology is introduced for the first time in the UK market by a “technology pioneer”, or “innovator”. A firm is coded as “imitator” when it adopts for the first time in one of its new handset models the technology previously introduced by the pioneer. In our analysis we want to consider only the imitation of *new* product technologies, namely those technologies only recently introduced and *not* widely adopted by competitors. We consider a product technology to be *widely adopted* by industry members if it has been installed in more than 50% of all products launched in the market. Above this level of adoption, imitation of the technology is no longer motivated by direct rivalry, but by recognition that consumers now see these features as intrinsic to the basic design and thus will not purchase handsets that lack these features. In total, we observed about 600 imitative actions by firms that fitted this criterion.

Since technologies may evolve over time, we follow the suggestion of Giachetti and Dagnino (2015) and analyze new product technology imitation by considering both the first version of a technology introduced in the market, and successive improvements. A list and description of the sampled product technologies is presented in the Appendix A.

It is important to bear in mind that handsets compete by offering consumers functionalities that are made possible by product technologies. In some instances, similar functionalities may be offered by different product technologies. Following the work on complex systems of Murmann and Frenken (2006), we define a “technological system” as a group of technologies allowing the product to perform functions of a certain type. For example, in mobile phones both infrared, Bluetooth and USB port are technologies allowing connectivity between devices, and thus belong to the same technological system. We grouped the 48 technologies in seven technological systems: networking, high speed data transfer, phone call, connectivity, messaging, display, technological convergence (see the Appendix A, Table A1).

As can be expected, we found innovation and imitation in all the technologies in our sample. However, when we examine the frequency of both, we also found that over the analyzed time period, the average number of new product technologies introduced every year, i.e. innovations, is much lower than the average number of imitations (see Figure A1 in Appendix A). This finding corroborates what is noted by previous studies: imitation is far more pervasive than innovation. Thus, firms may forgo the risks of innovative moves, but they cannot avoid imitation without suffering erosion of their market position (Lee et al. 2000; Levitt, 1966). It is also interesting to note that the average number of imitations rapidly increased until 2003, but started decreasing from 2004, and the average number of innovations was relatively high until 2003, declined in 2004 and then leveled off from then on. The main reason for this decline of innovations and imitations is the shift in the locus of technological innovation to smartphone devices. The regular phone market at this point in time enters a period of greater emphasis on price competition with consequent decline in the rates of innovation and imitation.

Measures

Dependent and independent variables. Depending on the relationship modeled in the proposed Red Queen competitive imitation cycle (Figure 1), we rely on a different set of dependent and independent variables. We assume that the focal firm's imitative actions at a certain time t trigger rivals response in the following time t+1, and both the focal firm's imitative action and rivals' response will affect the focal firm's performance at time t+2, as illustrated in Figure 1. Setting dependent and independent variables in a logical temporal sequence is important to make realistic assumptions about the fact that actions and reactions are deliberate, and they take some time before having an effect on performance.[7] Dependent and independent variables detailed description as follows:

Scope of the focal firm's imitation of new product technologies [at year t]. Consistent with the extant literature (Derfus et al., 2008), we define and measure the *scope of a firm's imitation* as the total number of new product technologies (belonging to a specific technological system) imitated by the focal firm within the year t.

Average speed of the focal firm's imitation of new product technologies [at year t]. We measure the *average speed of focal firm's imitation* as the average time it takes for the focal firm to imitate new product technologies related to a specific technological system. Essentially, we want to capture the speed of imitation of those new product technologies used to operationalize the imitation scope. To do this, we first computed the time to imitation, in months, per each of the technologies imitated by the firm in a certain year t. Second, we normalized this latter value by dividing it for the maximum imitation time for that technology in the sample, so as to transform the variable from count to ratio. Third, we computed the mean of the firm's imitation timing of technologies belonging to a certain technological system i ($avtime_{i,t}$). We finally operationalized the average speed of the focal firm's imitation ($AS_{i,t}$) as in equation 1. The resulting measure ranges from 0 to 1; the greater its value (i.e., closer to 1) the higher the focal firm's imitation speed.

$$AS_{i,t} = 1 - \left(avtime_{i,t}\right) \tag{1}$$

It is worth noting at this point that higher average speed of imitation does not entail higher imitation scope. In fact, two focal firms may have the same score for average imitation speed

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[7] Since the variable rivals' imitative response was computed at time t+1 and the variable 'focal firm performance' was computed at time t+2, our empirical analysis captures imitative actions between 1997 and 2007, and firm performance from 1999 and 2008.

but imitate a different number of technologies. Moreover, if one firm increases the number of technologies imitated from one year to another (i.e., wider scope), this might result in either higher or lower average speed with respect to the previous year (e.g., “lower speed” if the firm imitates a “higher number” of technologies, but “more slowly”).

Scope of rivals’ imitation of new product technologies [at year t+1]. We operationalized the *scope of a rivals’ imitation* by subtracting the total number of imitations realized by the focal firm at time t+1 from the total number of imitative actions taken by all competitors at the same time t+1 (in a focal technological system). In this way we account only for those imitative actions subsequent to the focal firm’s imitative actions.

Average speed of rivals’ imitation of new product technologies [at year t+1]. As in other competitive dynamics research (e.g., Ferrier et al., 1999; Young et al., 1996), we use rivals’ imitation speed as a measure of the average length of time it took rivals to act after a new product technology is introduced. Following the procedure outlined by Derfus et al. (2008), we calculate this measure by taking the mean of the average speed of imitation of all focal firm’s rivals at a certain time t+1. The resulting measure ranges from 0 to 1, with the higher rivals’ imitation speed for values closer to 1.

Focal firm performance [at year t+2]. Focal firm performance was operationalized using the number of handsets sold on a yearly basis (i.e., sales performance) in the UK. This measure of firm performance is widely used by mobile phone industry specialists such as Gartner Dataquest and Mintel International Group Limited. Data on handsets sold per vendor were collected from Mintel International Group Limited (1997–2008), Euromonitor International (2003–2008) and firms’ archival data.

Product technology heterogeneity [at year t]. We operationalized the measure of product technology heterogeneity using the Shannon entropy index (Shannon, 1948). This entropy measure is suitable for our research setting because it captures the extent to which products differ in terms of technologies that belong to a given technological system. A uniform distribution of the type of technologies products are equipped with reflects a situation in which firms produce a wide variety of designs, while a skewed distribution represents a situation in which there are minor differences between firms' choice of design. As such, the index can be used as an indicator of technological heterogeneity (Frenken, Saviotti & Trommetter, 1999), a situation in which products offered by industry rivals widely differ in terms of the technologies they are equipped with. The Shannon entropy value of a technological system is given by the following equation 2:

$$H_{i,t} = -\sum_{k=1}^{S} \ln(p_{k,t}) \times p_{k,t} \quad (2)$$

Where $H_{i,t}$ is the level of product technology heterogeneity within the technological system i at year t, $p_{k,t}$ is the percentage of products (introduced in year t) equipped with the technology k (therefore $0 \leq p_k \leq 1$), S is the number of technologies introduced and related to the technological system i.

The Shannon entropy index ($H_{i,t}$) is equal to zero when all products introduced at time t in the market are equipped with the same set of technologies related to the technological system i. This means that there is a dominant design in terms of the set of technologies related to i. In this extreme case, $p_{k,t}$ would be equal to 1, which implies that the entropy of the product population equals zero:

$$H_{i,t} = -\ln(1) \times 1 = 0 \quad (3)$$

Entropy is positive otherwise, and the larger its value, the larger is the variety in the population. Specifically, the larger the value of $H_{i,t}$: (a) the higher the number of technologies in the technological system; and (b) the lower is the diffusion of these technologies among existing products.

Control variables. We also included various control variables (those related to the focal firm and at the industry-level are computed at year *t*, those related to rivals are computed at year *t*+1), potentially affecting all firms' action and performance:

Focal firm innovation scope. Although we are analyzing competitive dynamics that are triggered by imitative efforts, we must control for imitation that occurs as a response to innovations introduced into the technological system, or what we call "innovation scope". This is in line with first-move advantage literature, which suggests that innovators' monopoly profits will attract imitative entrants (Lieberman & Montgomery, 1988; Markides & Geroski, 2004). This variable was measured as a count of new product technologies introduced by the focal firm in the year *t*.

Rivals innovation scope. Similar to what we did to measure a focal firm innovation scope, we measure rivals' innovation scope as a count of the new product technologies introduced by rivals in the year *t*+1.

Focal firm relative market position. Studies of the Red Queen effect have argued that a firm's relative size can influence its performance and rivals' response to its actions (Derfus et al., 2008). Relative market position was measured with a dummy variable that sets the value 1 if the level of sales of the firm in the year *t* was above the industry median, and 0 otherwise.

Focal firm largest product launch within the year. Mobile phone vendors may follow different strategies, depending on the time of year in which they introduce the largest number of new product models. We control for this strategic decision with a set of dummy variables that equal 1 during the quarter when the firm introduced the largest number of new product models during the year *t*, and equal 0 otherwise.

Industry concentration. Research in industrial organization and strategy has shown that industry concentration can influence the intensity of competition (Derfus et al, 2008). In an industry with high barriers to entry, such as the mobile phone industry, a higher level of industry concentration usually results in lower level of competition intensity because rivals with the largest market share are more likely to collude on their marketing strategies (Waldman & Jensen, 2012; Wiggins & Ruefli, 2005). We therefore control for industry concentration by using the cumulative market share of the four largest UK handset vendors as a measure.

GDP volatility. A three-year standard deviation of the UK gross domestic product (GDP) was used to account for the country macroeconomic uncertainty (Haddow, Hare, Hooley, & Shakir, 2013).

RESULTS

Hypotheses Testing

Table 1 reports variables descriptive statistics while Tables 2-3 report results of the regression analysis. We tested the hypotheses with three regression models: (1) a robust fixed-effects regression when the dependent variable is the focal firm performance (Table 2); (2) a robust fixed-effects regression when the dependent variable is rivals' average speed of imitation (Table 3); (3) a robust fixed-effects Poisson regression when the dependent variable is rivals' imitation scope, a count-type variable (Cameron & Trivedi, 2009) (Table 3). Hausman test suggested the use of fixed-effects was preferable than random-effects. Since not all technologies were adopted by all sampled firms, and not all firms were active in the UK market over the entire time period analyzed, we end up with a 566 observation-unbalanced panel.

Please insert Table 1-3 around here

Models 1-3 in Table 2 report the results for regressions relating focal firm imitation scope and speed, and rivals imitation scope and speed to firm performance (Hypotheses 1, 3, 4 and

6). The regression results that examine the impact of focal firm imitation scope and speed on rivals' imitation scope and speed respectively are presented in Table 3, Models 4-9 (Hypotheses 2 and 5). We calculated variance inflation factors (VIFs) to determine whether there was multicollinearity in the analyses. The average VIF scores were all below 1.4, and no individual VIF was greater than 2.08, thereby less than the recommended threshold of 10 (Chatterjee & Hadi, 2006).[8]

Before we turn to a discussion of the coefficients of independent variables and moderators related to the presented hypotheses, we briefly examine the coefficients of the control variables in the full Models 3 (Table 2), 6 and 9 (Table 3). We found the impact of *innovation scope* on focal firm performance, as shown in Model 3 (Table 2), in terms of both focal firm innovation scope (β=0.00, p>.1) and rivals' innovation scope (β=-0.00, p>.1), to be not significant. With regard to the impact of innovation scope on imitative actions, as shown in Models 6 and 9 (Table 3), we found that the only significant relationship is the one between rivals' innovation scope and rivals' imitation scope (Model 6: β=0.26, p<.01), showing that rivals that innovate more are also those that imitate more.[9] We also found that the control variable *relative market position* has a significant effect only on focal firm performance as shown in Model 3 (β=0.27, p<.01). As for industry-level controls, *industry concentration* has a negative and significant effect on rivals' average speed of imitation (Model 9: β=-0.33, p<.01), while *GDP volatility* has a positive effect on focal firm performance (Model 3: β=0.05, p<.01) and a negative effect on rivals' imitative actions (Model 6: β=-0.07, p<.05; Model 9: β=-0.23, p<.01).

[8] As can be observed in the correlation matrix presented in Table 1, the greatest correlation coefficient is that between focal firm imitation scope and speed (ρ=0.633; p<.01), two key independent variables in our regression model. In the regression models, the maximum variance inflation factors for these two variables were 2.08 and 1.79, respectively.

[9] The positive association between a firm's imitation scope and innovation scope can be observed also in the correlation matrix presented in Table 1: the correlation coefficients between rivals' imitation scope and rivals' innovation scope (ρ=0.353, p<.01) and between focal firm's imitation scope and focal firm's innovation scope (ρ=0.082, p<.1) are both positive and significant. We believe the explanation is that firms with greater resources and the capabilities needed to imitate several technologies have also greater resources and capabilities to introduce several technologies that are new to the market, and vice versa.

We turn now our attention to the hypotheses tests. Hypothesis 1a and 1b state that focal firm imitation scope and average speed of imitation have both a positive effect on its performance. As shown in Model 3 (Table 2), while the sign and significance of focal firm average speed of imitation is in line with our prediction (β=0.07, p<.05), focal firm imitation scope is significant with opposite sign (β=-0.08, p<.05). Therefore Hypothesis 1b is supported while Hypothesis 1a is not.

Hypothesis 2a states that as the scope of the firm's imitation of new product technologies increases, the scope of rivals' imitation of new product technologies will also increase. Hypothesis 2b states that as the average speed of the firm's imitation of new product technologies increases, the average speed of rivals' imitation of new product technologies will also increase. As can be observed in Table 3, in Model 6 the relationship between the scope of the focal firm's imitation and the scope of rivals' imitation is positive and significant (β=0.15, p<.01), while in Model 9 the relationship between the average speed of the focal firm's imitation and the average speed of rivals' imitation is positive but not significant (β=0.02, p>.1). Therefore, Hypothesis 2a is supported, while Hypothesis 2b is not.

Hypothesis 3a states that with the scope of the focal firm's imitation of new product technologies held constant, as the scope of rivals' imitation of new product technologies increases, focal firm performance decreases. Hypothesis 3b leads us to expect that holding the average speed of the focal firm's imitation of new product technologies constant, we shall observe decreasing focal firm performance as the average speed of rivals' imitation of new product technologies increases. As seen in Models 3 (Table 2), the coefficient of scope and average speed of rivals' imitation are both negative and significant (β=-0.04, p<.05; β=-0.05, p<.1), thus supporting both Hypotheses 3a and 3b.

Hypothesis 4a states that product technology heterogeneity negatively moderates the relationship between the focal firm scope of imitation of new product technologies and its performance. Hypothesis 4b states that product technology heterogeneity negatively moderates the relationship between the focal firm average speed of imitation of new product technologies and its performance. As shown in Model 3, the coefficient of the interaction between focal firm imitation scope and product technology heterogeneity is positive and significant (β=0.05, p<.05), and the coefficient of the interaction between focal firm imitation speed and product technology heterogeneity is not significant (β=0.00, p>.1). Hypothesis 4a and 4b are thus not supported.

Hypothesis 5a predicted that product technology heterogeneity negatively moderates the relationship between the scope of the firm's imitation of new product technologies and the rivals' scope of imitation of new product technologies. Hypothesis 5b predicted that product technology heterogeneity negatively moderates the relationship between the average speed of the firm's imitation of new product technologies and the rivals' average speed of imitation of new product technologies. As shown in Model 6, the coefficient of the interaction between focal firm's imitation scope and product technology heterogeneity is negative and significant, as expected (β=-0.09, p<.05), while in Model 9 the coefficient of the interaction between focal firm's imitation speed and product technology heterogeneity is negative but not significant (β=-0.02, p>.1). Hypothesis 5a is thus supported while Hypothesis 5b is not.

With Hypothesis 6a we predicted that product technology heterogeneity negatively moderates the relationship between the scope of the rivals' imitation of new product technologies and focal firm performance. With Hypothesis 6b we predicted that product technology heterogeneity negatively moderates the relationship between the average speed of the rivals' imitation of new product technologies and focal firm performance. As shown in Model 3, the coefficient of the interaction between rivals' imitation scope and product technology heterogeneity is negative and significant, as expected (β=-0.04, p<.05), while the coefficient of the interaction between rivals' imitation speed and product technology heterogeneity is negative but not significant (β=-0.00, p>.1). Hypothesis 6a is thus supported only while Hypothesis 6b is not.

Table 4 offers a summary of the predicted hypotheses and those that were supported by the empirical analysis. As can be observed, the Red Queen competitive imitation cycle (Hypotheses 1-3) is supported for at least one type of imitative action in all time frames. In the discussion section we will present the plots of interaction effects and extend the interpretation of these findings.

Please insert Table 4 around here

Robustness Tests

We tested the robustness of our findings in several ways. First, we examined an alternative explanation to the one we advance in Hypotheses 1a and 1b. Specifically, if imitation scope rises, new product development costs will escalate, which in turn will lead to negative performance consequences. By the same token, as firms increase their imitation speed to catch up with their rivals, they have less time to adequately assess market response, and this in turn is likely to have negative performance consequences. Under both scenarios, we should expect an inverted U-shaped relationship between both types of imitative action and firm performance. To test these alternative predictions we repeated the regression analysis by adding the squared term of both focal firm imitation scope and average speed of imitation. We did not find the squared terms to be significant.

Second, we had to examine the robustness of our results in light of the fact that the dependent variables – average speed of imitation and imitation scope – are left- and right-censored respectively. Average speed of imitation is left-censored because it is a ratio that cannot be less than zero, and may take the value zero both when a firm has minimum average imitation speed and when the firm is not imitating any technology. Imitation scope is right-censored because the number of technological attributes available to be imitated has an upper limit. We therefore tested the full Models 6 and 9 (Table 3) using alternative models that took account of the censored nature of both dependent variables. More specifically, we repeated Models 6 and 9 using a Tobit fixed-effects regression based on the Honorè (1992) estimator with an absolute error loss function. This estimator was chosen because there is no conditional fixed-effects Tobit model, and the unconditional fixed-effects Tobit model is biased (Honorè, 1992). As shown in Table 5, Model 10 and 11, even with this alternative technique, results are consistent with those presented in Table 3.

Third, since the regression equations in Model 6 and 9 rely on the same set of independent variables, in order to account for potential correlations of the random error components of the two equations, we ran Model 6 and 9 using the Seemingly Unrelated Regressions (SUR) technique (Zellner, 1962). This method involves estimating separate equations for rivals' speed and scope of imitation while recognizing relationships across the two actions. As shown in Table 5, Model 12 and 13, results are consistent with those in Models 6 and 9, with the only exception of Hypothesis 5a (that presents the expected sign, but is not significant).

Please insert Table 5 around here

DISCUSSION

Implications

This study aims to expand our understanding of competitive dynamics in technology-intensive industries with the lens of Red Queen competition. We did this by bringing together relevant research from competitive dynamics, imitation and technology innovation literatures. The more recent Red Queen literature analyzes the conditions under which competitive actions increase firm performance and trigger rivals' response (Derfus et al., 2008), but has not paid sufficient attention to: (a) the analysis of Red Queen competitive dynamics in technology-intensive industries; (b) the role of different types of imitative actions in sustaining and triggering the Red Queen cycle, and (c) how changes in the technological environment moderate the Red Queen cycle. To address these gaps we have developed a model of Red Queen competition where the scope and speed of imitation of new product technologies is the result of competitive threats by rivals' imitative actions. The competitive race predicted by our theory of Red Queen competitive imitation implies that firms struggle to: (a) learn which technologies are and will be successful in the market; (b) imitate new product technologies to maintain competitive parity with rivals; and thus (c) adapt to the evolving technological environment. The analysis of this self-reinforcing competitive mechanism enables us to shed light on the positive and negative aspects of different types of imitative action and to clarify the relative importance of these aspects with regard to firm performance.

Our first result shows that focal firms' average speed of imitation positively affects their sales performance (Hypothesis 1b) while, contrary to our prediction, focal firms' imitation scope has a detrimental effect on performance (Hypotheses 1a). Results of speed are consistent with previous findings of the competitive dynamics literature (D'Aveni, 1994; Lee et al., 2000). By contrast, the negative effect of scope on focal firm performance is apparently counterintuitive. We will consider this result again later in this section, since the imitation scope-performance relationship turns out to be positive when considering the moderating effect of product technology heterogeneity. In line with the Red Queen argument, we also found that focal firm imitation scope triggers rivals imitation scope (Hypothesis 2a), but focal firm speed of imitation does not trigger rivals' rapid imitation (Hypothesis 2b). There are two possible interpretations of these results. One, it is possible that rivals perceive scope as more of a threat to their competitive positions then speed, and thus are more likely to invest resources matching scope rather than speed; or, two, rivals may not be able to move as quickly as the focal firms that were the earliest, if not the first, to make the imitative moves. Either way, whether rivals *choose* to focus resources on scope over speed, or *cannot marshal* the resources to respond quickly - rivals definitely respond to scope moves, implying that scope is an important strategic issue in technology-intensive industries. These results contrast in part with those studies in the competitive dynamics literature that describe response speed as the main strategic issue firms focus resources on when countermoveing against rivals (Derfus et al., 2008; Markides & Geroski, 2004). Finally, to close the Red Queen cycle, we found that rivals' imitation scope and speed have a negative effect on the focal firm performance (Hypotheses 3a and 3b).

To illustrate our results, it may be useful to give an example. Nokia's pioneering of digital technologies such as infrared, games, email client and WAP during the 1990s, elicited various reactions from rivals. Siemens was among the first to imitate (high imitation speed) all of the technologies mentioned earlier (high imitation scope). This reinforced Siemens product portfolio competitiveness, and increased its sales performance relative to slower imitators like NEC, Philips and Sagem. Still, Siemens enjoyed a temporary competitive advantage that lasted until Nokia's innovations were adopted by other handset vendors. Subsequently, at the beginning of the 2000s, some vendors pioneered new product technologies such as Bluetooth, MMS and photo-camera, and a new series of imitative actions commenced, with firms like Sony-Ericsson and Samsung installing this set of features in their new lines of phones more quickly than Siemens. Although in the first time period (i.e., during the 1990s) Siemens was able to match the scope and speed requirements, and in turn enjoyed a temporary competitive advantage, in the second time period (i.e., beginning of the 2000s) it did not possess the imitative capabilities to stay aligned with rivals, and struggled to catch up. To paraphrase

Lewis Carroll (1960), Siemens realized that although it was running as fast as it could, it was not getting anywhere, relative to its rivals. Interestingly, the escalating pressure to imitate in order to retain market position, not only increased “competitive imitation” among handset vendors, but also accelerated the technological evolution of the industry. In fact, looking back it is remarkable how quickly the industry moved in a few years from basic handsets capable to provide only phone calls in the mid-1990s, to multi-tasking devices that integrate nearly all types of portable technologies (Figure A1).

In order to get a clearer picture of the boundaries of the Red Queen competition in a technology-intensive industry, we also examined to what extent Red Queen evolution may depend upon a specific industry condition, in our case, the level of product technology heterogeneity in the market. We found product technology heterogeneity to have a significant moderating effect in all time frames of the proposed Red Queen competitive imitation cycle, for at least one type of imitative action (Table 4). First, contrary to our prediction in Hypothesis 4a, our results indicate that product technology heterogeneity significantly and positively moderates the effect of focal firm imitation scope on the focal firm performance. This result, combined with the negative direct effect of firm imitation scope on its performance, is represented in Figure 2. More specifically, when we plot the data of the significant interaction (i.e., scope of focal firm imitation × product technology heterogeneity), we observe that: (1) the effect of focal firm imitation scope on its performance is positive for high levels of product technology heterogeneity, while it is negative for low levels of product technology heterogeneity, and (2) performance gains from focal firm imitation scope are maximized when focal firm imitation scope is large, and product technology heterogeneity is high. The overall picture shows that imitation scope may indeed have a positive effect on firm performance as predicted in Hypothesis 1a, but this occurs only for high levels of product technology heterogeneity. Ex post, an explanation for this result could be that when product technology heterogeneity is high focal firms have to imitate as many new technologies as they can in order to increase the probability of launching new product models that converge with the product configuration that will become dominant.

Moreover, as predicted in our theory, we found that product technology heterogeneity negatively moderates the relationship between the focal firm imitation scope and rivals imitation scope. This is because when product technology heterogeneity is high, the focal firm and rivals' learning process is constrained. Rivals that react to the focal firm's moves are more likely to be conservative when it comes to the number of new technologies imitated, preferring to wait until the technological uncertainty decreases. Overall, these findings are consistent with what observed by other studies in the Red Queen literature, namely that learning from competitive experience will be less effective if firms encounter a series of environmental shocks that render their learning capability obsolete (Barkema et al., 2002; Derfus et al., 2008). Bearing in mind that product technology heterogeneity changes, which in turn influences the pace of technological change, we believe that our results also contribute to research on how technological changes in technology-intensive industries may influence the way firms compete (Agarwal, Sarkar, & Echambadi, 2002; Utterback & Suarez, 1993), as well as their ability to preserve their performance vis-à-vis rivals (Bayus & Agarwal, 2007).

In line with our predictions, we also found that product technology heterogeneity negatively moderates the effect of rivals' imitation scope on the focal firm performance. When products differ highly in term of the technologies they incorporate, rivals' imitative response to focal firm actions will disproportionately decrease the focal firm performance. The main reason, as we see it, is that rivals have an imitative advantage when the focal firm confronts greater uncertainty about the performance of new technologies. Rivals can observe the performance outcomes of the focal firm's imitative action and then imitate (in the following period) only new technologies that have demonstrated greater acceptance by consumers. In this way, rivals strengthen their competitive position with respect to the focal firm by investing only in value enhancing technologies. Plotting the data from the Model 3 we graphically represent the form of the significant interaction (i.e., scope of rivals' imitation × product technology heterogeneity) in Figures 3. Specifically, we see in Figure 3 the actual scope of rivals' imitation and product technology heterogeneity associated with various levels of performance. As expected, the relationship between scope of rivals' imitation and focal firm performance is more negative for high levels of product technology heterogeneity.

It is worth noting that although not directly predicted in our theory, our regression analysis offers interesting results on the impact of product technology heterogeneity on firm performance and on rivals' imitative actions. Model 3 (Table 2) and Figure 2 and 3 show that product technology heterogeneity has a positive effect on focal firm performance. In fact, when product technology heterogeneity is high, products introduced by industry members are very heterogeneous, and direct competition is likely to be relatively weak, since each firm in the industry attempts to carve out its own unique product niche. Thus, although we found that product technology heterogeneity may create uncertainty and hamper the effectiveness of focal firms imitative actions, overall firms tend to achieve higher performance in this scenario. As for the direct effect of product technology heterogeneity on rivals' imitative actions, we found the effect is positive on rivals imitation scope (Model 6, Table 3), while the effect is negative on rivals average speed of imitation (Model 9, Table 3): higher heterogeneity in product designs triggers imitative responses aimed at catching the opportunities offered by the variety of available technologies, but the propensity to imitate several different technologies limits the rivals' ability to imitate them rapidly.

Finally, although our paper looks at Red Queen competition primarily from the point of view of key competitive moves that involve imitation of new product technologies, which in turn triggers rivals' imitative response (Figure 1), we want to take into account also the possibility that rivals respond to the focal firm's imitative actions with their own innovations. In Table 6, Models 14-16, we report the analysis of the effect of a focal firm's imitative actions on rivals' innovation scope. Given the excess of zero counts in the rivals' innovation scope dependent variable, a zero-inflated Poisson regression was used (Cameron & Trivedi, 2009). Model 16 is the full model taking into account also the moderating effect of product technology heterogeneity. As can be observed in Model 16, while focal firm average speed of imitation has no significant impact on rivals innovation scope (β=0.05, p>.1), the impact of focal firm imitation scope is negative and significant (β=-0.20, p<.1). This result should be read together with the positive effect of the focal firm imitation scope on rivals imitation scope we found in Model 6: as the focal firm imitative action (scope) increases, rivals tend to respond with imitation at the expenses of innovation.

Please insert Figures 2 and 3 and Table 6 around here

Limitations and Avenues for Future Research

As may be expected, our study has limitations, some of which create opportunities for future research. First, as is the case in most of empirical studies in competitive dynamics, our study captures only observable strategies based on information reported in the press and industry trade journals we examined. However, given the fact that mobile phones regularly incorporate technologies that originate in other product categories such as digital cameras, MP3 player, video game, it is likely that mobile phone vendors in our sample are influenced by technological decisions made by actors from other industries. This caveat applies to the UK as well as global mobile phone sales. Consequently, future research could examine how country and industry boundaries influence the Red Queen competitive imitation.

Second, our study examines an industry defined by a single product, the mobile phone. Red Queen competition in this case is likewise focused primarily on improvements to this device. Empirically, studying an industry that is defined by a single product is an advantage in as much at it provides a context that allows us to examine Red Queen competition with greater precision. However, this advantage is also a limitation given the fact that competition in many industries, for example food retailing, is multi-product. It can be reasonably expected that product line diversity will produce different action-reaction dynamics than is the case when competition is focused on a single device. For example, the pressure to respond to a rival's move in one segment of the market may be lower if the focal firm sees potential losses as minor relative to the performance of its entire product portfolio. Our results for imitation scope and speed may be generalizable to other industries where single products drive competition, but may not be generalizable for multi-product industries. Future research is clearly needed to extend the findings of our study to industries where competition engages firms that offer consumers a wide range of products.

Third, although we contend that product technology heterogeneity can affect the way firms learn from the technology adoption decisions of rivals, and undertake actions accordingly, scholars of organizational learning have identified a variety of learning mechanisms, e.g. mimetic, vicarious, experiential (Baum et al., 2000; Haunschild & Miner, 1997; Lieberman & Asaba, 2006), that are not captured in our theory and empirical analysis. Whether firms select one mode of learning over another depends on their resource endowment and the time they can wait before committing to a decision, with inevitable different impacts on the type and effectiveness of their imitative actions. It would be useful for future research to develop appropriate measures of different learning modes as well as provide theoretical basis for these measures.

Finally, analysis of Red Queen competition is usually studied through the lens of inter-firm rivalry, with an interest in how firms react to each other's moves. However, Derfus et al. (2008) suggest that it is also important to see Red Queen competition as a link between micro and macro industry dynamics. They note, for instance, that new product introductions moves may represent "positive sum" game in which the race to introduce products with more features and better technologies can increase consumer demand for the industry as a whole. Paradoxically, therefore, Red Queen competition can lead to a competitive stalemate at the level of individual firms, while at the same time producing greater benefits for all to share. The same can be said for technological change. Firms introduce new products and new technologies in order to retain their position, but in the process of doing so they move the industry's technological frontier forward. In principle, we can therefore say that Red Queen competition often plays an important role in linking competitive interactions at the micro industry level with macro industry dynamics (Felin, Foss, & Ployhart, 2015). This linking role is potentially a fruitful area of Red Queen competition research. Future research should therefore examine how different types of Red Queen competition impact the evolution of industries, and vice versa, how the evolution of industries shapes Red Queen competition.

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TABLE 1
Descriptive Statistics

		Mean	Sd	1	2	3	4	5	6	7	8	9	10	11
1	Focal firm performance (t+2)[a]	1797.207	2275.312	1.000										
2	Focal firm imitation scope (t)	0.514	0.824	0.080^{+}	1.000									
3	Focal firm average speed of imitation (t)	0.145	0.255	0.165**	0.633**	1.000								
4	Rivals imitation scope (t+1)	4.716	4.414	-0.064	0.295**	0.198**	1.000							
5	Rival average speed of imitation (t+1)	0.350	0.242	-0.174**	-0.071^{+}	0.036	0.090*	1.000						
6	Product technology heterogeneity (t)	1.457	0.868	0.144**	0.441**	0.196**	0.405**	-0.293**	1.000					
7	Focal firm innovation scope (t)	0.074	0.300	0.081^{+}	0.082^{+}	0.094*	0.109**	0.069	0.060	1.000				
8	Rivals innovation scope (t+1)	0.574	0.801	-0.104*	-0.049	-0.027	0.353**	0.187**	-0.089*	-0.001	1.000			
9	Focal firm relative market position (t)	0.495	0.500	0.611**	0.069	0.170**	-0.015	-0.052	0.032	0.050	-0.026	1.000		
10	Industry concentration (t)	0.776	0.048	0.079^{+}	0.019	-0.041	0.007	-0.245**	0.104*	-0.008	-0.002	0.080^{+}	1.000	
11	GDP volatility (t)[b]	10573.849	2683.771	-0.075^{+}	-0.222**	-0.091*	-0.122**	0.118**	-0.348**	-0.024	0.056	-0.054	-0.487**	1.000

[a] Units sold are expressed in thousands.
[b] GDP volatility is computed on GDP values in millions of pounds.
$N = 566$
$^{+}p < 0.10$
$^{*}p < 0.05$
$^{**}p < 0.01$

TABLE 2
Robust Fixed-effects Regression Analysis: Focal Firm and Rivals' Imitative Actions on the Focal Firm Performance

		Model 1 Focal firm performance (t+2)	**Model 2** Focal firm performance (t+2)	**Model 3** Focal firm performance (t+2)
Constant		-0.10**	-0.05*	-0.06**
		(-5.23)	(-2.47)	(-2.76)
Independent variables				
Focal firm imitation scope (t)	**H1a**		-0.04^{+}	-0.08*
			(-1.86)	(-2.43)
Focal firm average speed of imitation (t)	**H1b**		0.05*	0.07*
			(2.00)	(2.50)
Rivals imitation scope (t+1)	**H3a**		-0.05**	-0.04*
			(-2.76)	(-2.39)
Rivals average speed of imitation (t+1)	**H3b**		-0.04^{+}	-0.05^{+}
			(-1.98)	(-1.95)
Product technology heterogeneity (t)			0.12*	0.12**
			(2.62)	(2.99)
Interactions				
Focal firm imitation scope × Product technology heterogeneity	**H4a**			0.05*
				(2.03)
Focal firm average speed of imitation × Product technology heterogeneity	**H4b**			0.00
				(0.18)
Rivals imitation scope × Product technology heterogeneity	**H6a**			-0.04*
				(-2.31)
Rivals average speed of imitation × Product technology heterogeneity	**H6b**			-0.00
				(-0.12)
Controls				
Focal firm innovation scope (t)		-0.00	0.00	0.00
		(-0.28)	(0.17)	(0.16)
Rivals innovation scope (t+1)		-0.04*	0.00	-0.00
		(-2.26)	(0.08)	(-0.04)
Relative market position (t)		0.30**	0.28**	0.27**
		(5.04)	(5.40)	(5.32)
Industry concentration (t)		-0.01	-0.01	-0.02
		(-0.55)	(-0.56)	(-0.92)
GDP volatility (t)		0.04**	0.06**	0.05**
		(2.70)	(2.78)	(2.65)
2nd quarter year t (largest new product launch)		0.20**	0.15**	0.15**
		(4.96)	(3.84)	(3.86)
3rd quarter year t (largest new product launch)		0.12*	0.09*	0.10*
		(2.61)	(2.05)	(2.17)
4th quarter year t (largest new product launch)		0.03	0.01	0.01
		(0.69)	(0.15)	(0.36)
N		566	566	566
Within R-sq		0.24	0.30	0.31

Estimates are based on standardized variables; *t*-statistics in parentheses.

$^{+}p< 0.10$

$^{*}p< 0.05$

$^{**}p< 0.01$

TABLE 3
Robust Fixed-effects Regression Analysis: Focal Firm Imitative Actions on Rivals' Imitative Actions

		Robust fixed-effects Poisson			Robust fixed-effects		
		Model 4 Rivals imitation scope (t+1)	**Model 5** Rivals imitation scope (t+1)	**Model 6** Rivals imitation scope (t+1)	**Model 7** Rivals average speed of imitation (t+1)	**Model 8** Rivals average speed of imitation (t+1)	**Model 9** Rivals average speed of imitation (t+1)
Constant					0.25**	0.05	0.05
					(4.52)	(0.79)	(0.88)
Independent variables							
Focal firm imitation scope (t)	**H2a**		0.08^{+}	**0.15****		0.04	0.05
			(1.76)	**(3.11)**		(0.87)	(0.93)
Focal firm average speed of imitation (t)	**H2b**		0.06	0.02		0.02	**0.02**
			(1.61)	(0.67)		(0.52)	**(0.42)**
Product technology heterogeneity (t)			0.23**	0.23**		-0.62**	-0.61**
			(4.30)	(4.53)		(-14.78)	(-14.19)
Interactions							
Focal firm imitation scope × Product technology heterogeneity	**H5a**			**-0.09***			
				(-2.38)			
Focal firm average speed of imitation × Product technology heterogeneity	**H5b**						**-0.02**
							(-0.72)
Controls							
Focal firm innovation scope (t)		0.02	0.02	0.02	0.05	0.02	0.02
		(0.52)	(0.63)	(0.64)	(1.18)	(0.44)	(0.45)
Rivals innovation scope (t+1)		0.18**	0.26**	0.26**	0.09*	-0.03	-0.02
		(5.26)	(6.81)	(7.15)	(2.03)	(-0.56)	(-0.54)
Relative market position (t)		-0.05	-0.07	-0.05	-0.07	-0.01	-0.01
		(-1.11)	(-1.46)	(-1.13)	(-0.88)	(-0.22)	(-0.20)
Industry concentration (t)		-0.07	0.00	-0.00	-0.28**	-0.33**	-0.33**
		(-1.40)	(0.07)	(-0.10)	(-7.53)	(-10.15)	(-10.14)
GDP volatility (t)		-0.17**	-0.06^{+}	-0.07*	-0.07	-0.23**	-0.23**
		(-6.44)	(-1.94)	(-2.16)	(-1.45)	(-5.60)	(-5.60)
2nd quarter year t (largest new product launch)		-0.03	-0.12	-0.14	-0.32**	-0.09	-0.09
		(-0.31)	(-1.24)	(-1.42)	(-3.06)	(-0.85)	(-0.87)
3rd quarter year t (largest new product launch)		-0.04	-0.06	-0.08	-0.27*	-0.14	-0.14
		(-0.39)	(-0.58)	(-0.81)	(-2.24)	(-1.30)	(-1.32)
4th quarter year t (largest new product launch)		0.11	0.06	0.04	-0.19^{+}	-0.03	-0.04
		(1.25)	(0.63)	(0.38)	(-1.71)	(-0.32)	(-0.34)
N		566	566	566	566	566	566
Within R-sq					0.09	0.23	0.23
Wald Chi-square		86.25	113.00	132.65			

Estimates are based on standardized variables; in parentheses are reported *t*-statistics for robust fixed-effects and *z*-statistics for robust fixed-effects Poisson; coefficients in bold are those related to the tested hypotheses.

$^{+}p < 0.10$
$^{*}p < 0.05$
$^{**}p < 0.01$

TABLE 4
Predicted Hypotheses and Obtained Findings

Hypotheses	**Predicted relationship**	**Obtained findings**[a]	
		Imitation scope (Hypotheses a)	**Average imitation speed (Hypotheses b)**
1	Positive effect of a focal firm imitative actions on its performance	Negative[b]	**Positive**
2	Positive effect of a firm imitative actions on rivals' imitative actions	**Positive**	Not significant
3	Negative effect of rivals' imitative actions on focal firm performance	**Negative**	**Negative**
4	Negative moderating effect of product technology heterogeneity on the relationship between a focal firm imitative actions and its performance	Positive	Not significant
5	Negative moderating effect of product technology heterogeneity on the relationship between focal firm imitative actions and rivals actions	**Negative**	Not significant
6	Negative moderating effect of product technology heterogeneity on the relationship between rivals' imitative actions and focal firm performance	**Negative**	Not significant

[a] Relationships supported by the empirical analysis are in bold.
[b] Positive for high levels of product technology heterogeneity (Figure 2).

TABLE 5
Tobit Fixed-effects Regression and Seemingly Unrelated Regression Analysis: Focal Firm Imitative Actions on Rivals' Imitative Actions

		Tobit Fixed-effects		Seemingly Unrelated Regression[a]	
		Model 10 Rivals imitation scope (t+1)	**Model 11** Rivals average speed of imitation (t+1)	**Model 12** Rivals imitation scope (t+1)	**Model 13** Rivals average speed of imitation (t+1)
Constant				-0.13	-0.31
				(-0.47)	(-1.05)
Independent variables					
Focal firm imitation scope (t)	**H2a**	**0.38***	0.14	**0.15***	0.05
		(1.96)	(0.98)	**(2.54)**	(0.94)
Focal firm average speed of imitation (t)	**H2b**	0.06	**-0.15**	0.04	**0.02**
		(0.54)	**(-1.18)**	(0.80)	**(0.36)**
Product technology heterogeneity (t)		0.78**	-1.02**	0.33**	-0.61**
		(4.35)	(-6.55)	(5.35)	(-9.58)
Interactions					
Focal firm imitation scope × Product technology heterogeneity	**H5a**	**-0.25***		**-0.05**	
		(-2.27)		**(-1.04)**	
Focal firm average speed of imitation × Product technology heterogeneity	**H5b**		**-0.06**		**-0.03**
			(-0.89)		**(-0.72)**
Controls					
Focal firm innovation scope (t)		0.01	-0.03	0.02	0.02
		(0.08)	(-0.33)	(0.58)	(0.57)
Rivals innovation scope (t+1)		0.61**	-0.02	0.32**	-0.02
		(8.37)	(-0.21)	(8.44)	(-0.64)
Relative market position (t)		-0.19^{+}	0.04	-0.09	-0.01
		(-1.92)	(0.38)	(-1.44)	(-0.20)
Industry concentration (t)		-0.18^{+}	-0.57**	-0.02	-0.33**
		(-1.76)	(-3.96)	(-0.50)	(-7.32)
GDP volatility (t)		-0.07	-0.43**	-0.05	-0.23**
		(-0.73)	(-3.52)	(-1.19)	(-5.60)
2nd quarter year t (largest new product launch)		-0.53**	-0.04	-0.13	-0.09
		(-2.86)	(-0.23)	(-1.39)	(-0.98)
3rd quarter year t (largest new product launch)		0.09	-0.19	-0.05	-0.14
		(0.35)	(-1.07)	(-0.49)	(-1.42)
4th quarter year t (largest new product launch)		0.24	-0.32^{+}	-0.05	-0.04
		(1.05)	(-1.66)	(-0.49)	(-0.35)
N		566	566	566	566
R-sq				0.42	0.37
Chi-square		220.05	146.93	417.94	331.59

Estimates are based on standardized variables; *z*-statistics in parentheses; coefficients in bold are those related to the tested hypotheses.

[a] Firm dummies were included but not reported.

$^{+}p < 0.10$

$^{*}p < 0.05$

$^{**}p < 0.01$

TABLE 6
Robust Zero-inflated Poisson Regression Analysis: Focal Firm Imitative Actions on Rivals' Innovation Scope

	Model 14 Rivals innovation scope (t+1)	**Model 15** Rivals innovation scope (t+1)	**Model 16** Rivals innovation scope (t+1)
Constant	-0.13	-0.75^{**}	-0.85^{**}
	(-1.10)	(-6.99)	(-7.47)
Independent variables			
Focal firm imitation scope (t)		-0.05	-0.20^{+}
		(-0.55)	(-1.69)
Focal firm average speed of imitation (t)		-0.03	0.05
		(-0.44)	(0.62)
Rivals imitation scope (t+1)		0.51^{**}	0.52^{**}
		(12.71)	(12.57)
Rivals average speed of imitation (t+1)		0.22^{**}	0.20^{*}
		(2.58)	(2.36)
Product technology heterogeneity (t)		-0.30^{**}	-0.29^{**}
		(-2.87)	(-2.78)
Interactions			
Focal firm imitation scope × Product technology heterogeneity			0.19^{+}
			(1.72)
Focal firm average speed of imitation × Product technology heterogeneity			-0.04
			(-0.43)
Controls			
Focal firm innovation scope (t)	-0.01	-0.03	-0.03
	(-0.20)	(-0.61)	(-0.66)
Relative market position (t)	0.03	0.02	0.01
	(0.51)	(0.38)	(0.24)
Industry concentration (t)	0.11	0.07	0.09
	(1.31)	(0.68)	(0.96)
GDP volatility (t)	0.08^{+}	0.04	0.05
	(1.73)	(0.56)	(0.82)
2nd quarter year t (largest new product launch)	-0.21	-0.08	-0.07
	(-1.36)	(-0.58)	(-0.47)
3rd quarter year t (largest new product launch)	-0.16	-0.08	-0.05
	(-0.98)	(-0.51)	(-0.32)
4th quarter year t (largest new product launch)	-0.18	-0.06	-0.03
	(-1.15)	(-0.38)	(-0.18)
N	566	566	566
Log-likelihood	-568.95	-518.29	-515.55
LR Chi-square	7.49	180.11	187.05

Estimates are based on standardized variables; *z*-statistics in parentheses.
$^{+}p < 0.10$
$^{*}p < 0.05$
$^{**}p < 0.01$

FIGURE 1
Research Model

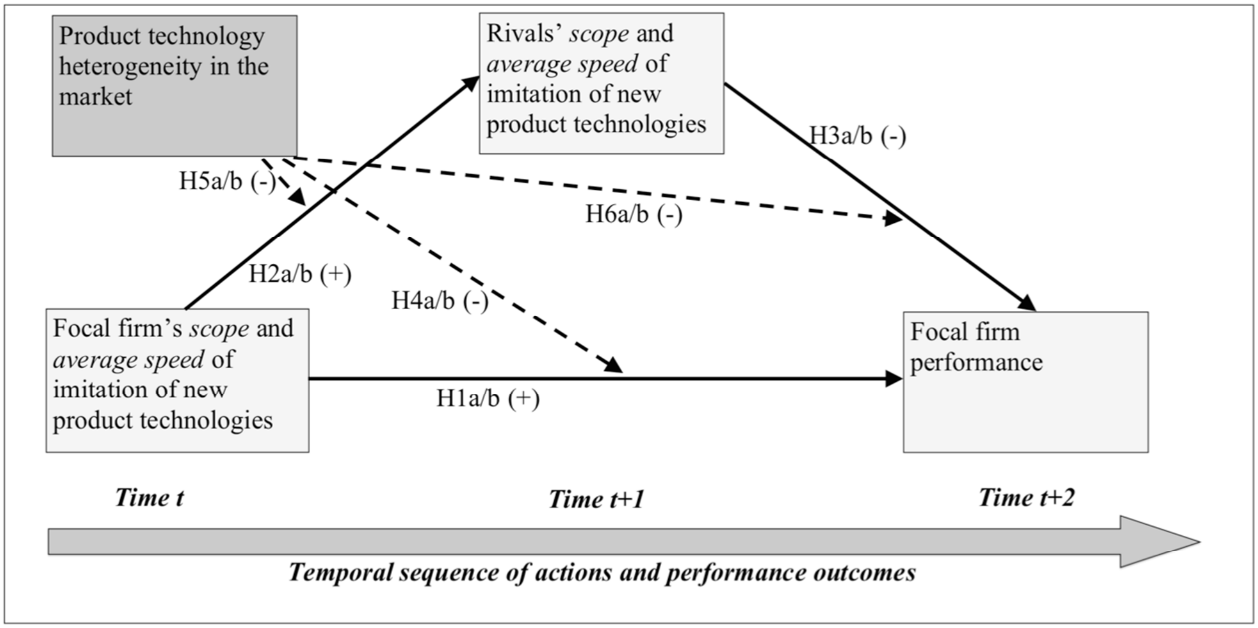


FIGURE 2
Scope of Focal Firm's Imitation, Product Technology Heterogeneity and Focal Firm Performance

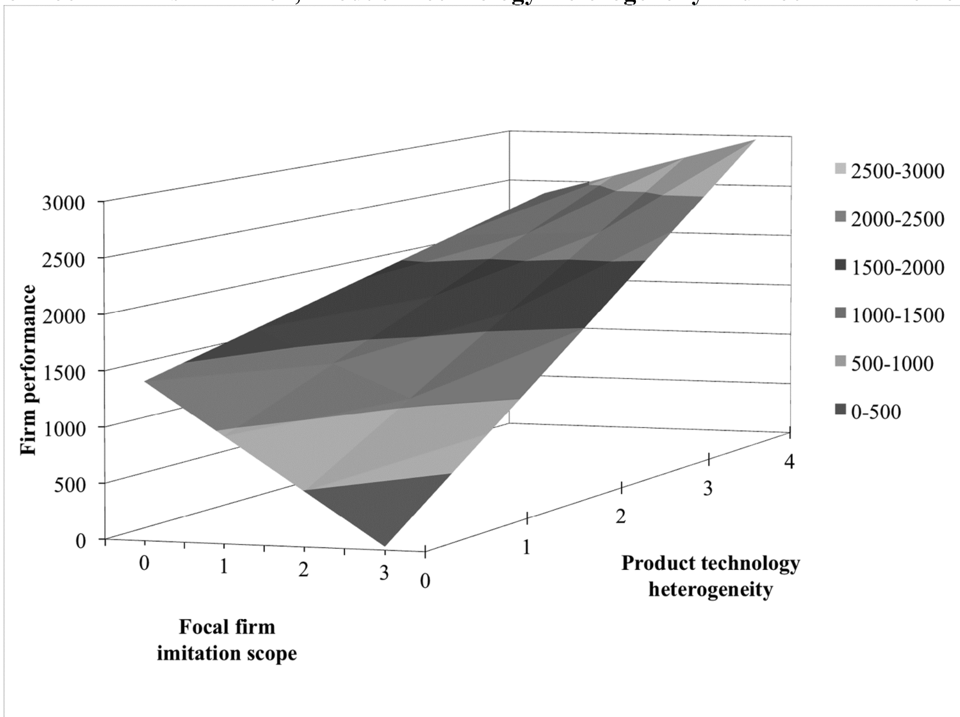
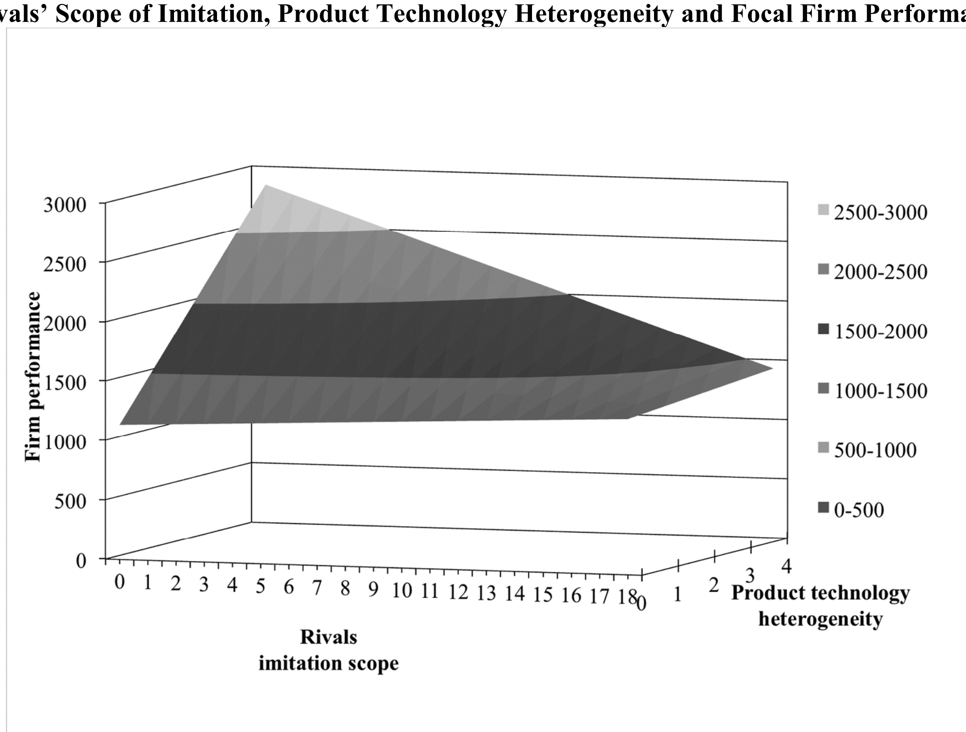


FIGURE 3
Rivals' Scope of Imitation, Product Technology Heterogeneity and Focal Firm Performance



APPENDIX A

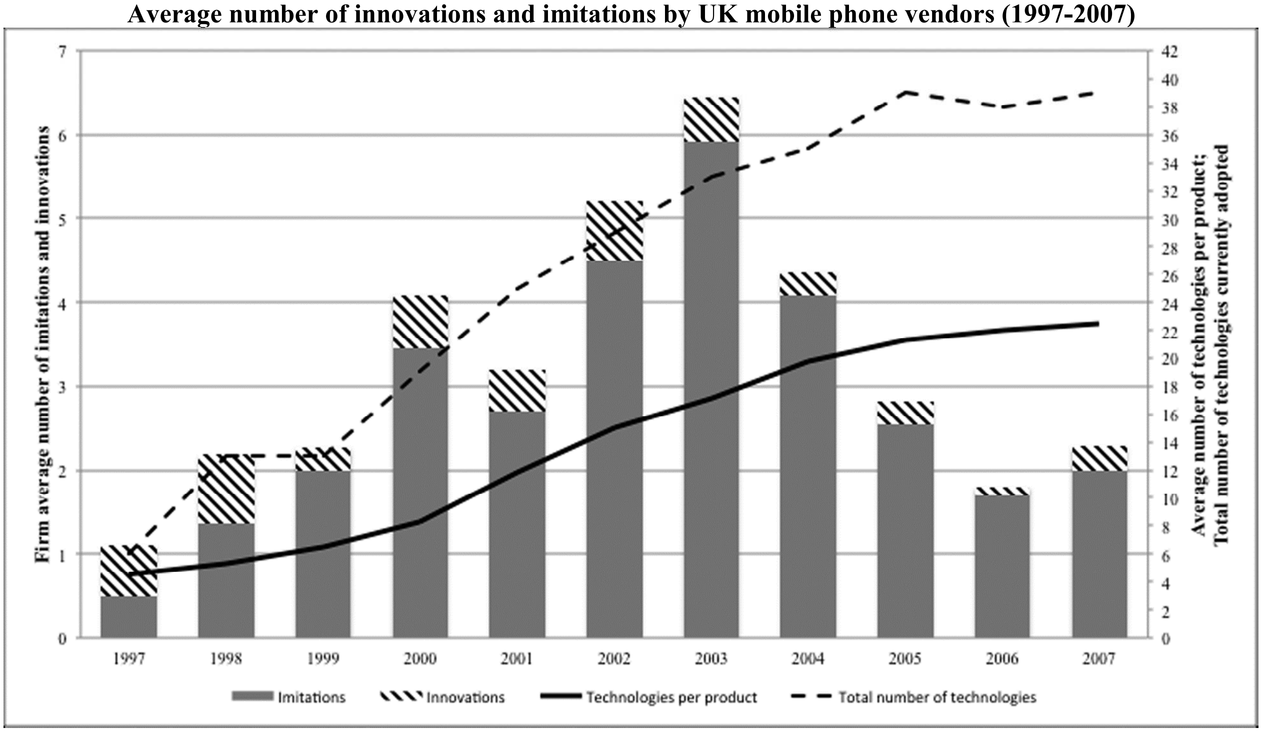
TABLE A1
Product Technologies Introduced in the UK Mobile Phone Industry from 1997 to 2007

Technological system	Type of functions offered	List of technologies (month of introduction in the UK market)	Description
Networking	Mobile phone networks use signals on specific frequency bands. Phones must be compatible with these bands in order to work with the network.	*Dual-band* (Feb-1998)	A phone ability to work with two of the four major GSM frequency bands. An important feature for users who wish to use the same handset in different locations where the networks work on different bands. For example, some European dual-band phone won't work in the US, and vice versa.
		Tri-band (Aug-1999)	A phone ability to work with three of the four major GSM frequency bands, allowing it to work in most parts of the world.
		Quad-band (Oct-2003)	A phone ability to work with the four major GSM frequency bands (850/900/1800/1900 MHz), making it compatible with all the major GSM networks in the world.
		WCDMA (Mar-2003)	A third-generation wireless standard, which allows use of both voice and data. It has different frequency bands (Europe and Asia - 2100MHz, North America - 1900MHz and 850MHz).
High speed data transfer	Mobile phone networks support different types of data transfer, which allows to use mobile internet, MMS up to the most advanced features as live, streaming video.	*HSCSD* (Nov-2000)	A system for data calls on GSM networks that came before packet-based systems such as GPRS and EDGE. It was never widely adopted outside Europe.
		GPRS (Mar-2001)	General Packet Radio Service is a packet-switching technology that enables data transfers through cellular networks. It is used for mobile internet, MMS and other data communications. Informally, GPRS is also called 2.5G.
		EDGE (Feb-2004)	A data system used on top of GSM networks. It provides nearly three times faster speeds than the outdated GPRS system. EDGE meets the requirements for a 3G network but is usually classified as 2.75G.
		UMTS (Mar-2003)	This includes high data speeds (2Mbps), always-on data access, and greater voice capacity, enabling such advanced features as live, streaming video.
		HSDPA (mar-2007)	An upgrade for UMTS networks that doubles network capacity and increases download data speeds by five times or more.
Phone call	Phone call functionalities refer to the way the user can make a phone call (e.g., voice dialing the number), the type of call (i.e., voice vs. video), and the type of call alert (the mobile phone can alert the user of events such as an incoming call or an incoming message in a number of ways).	*Vibrate alert* (Jan-1997)	This can alert events such as an incoming call, or an incoming message with a vibrate alert.
		Voice Dial (Jul-1997)	This allows the user to dial a number by a voice command.
		Polyphonic ringtones(Jan-2000)	This creates realistic-sounding music by synthesizing several notes simultaneously. The more notes the synthesizer can play simultaneously, the richer the musical effect. Usually mobile phones synthesizers can reproduce from 4 to 72 simultaneous tones.
		True tones (Feb-2003)	Audio recordings, typically in a common format such as MP3, AAC, or WMA.
		Downloadable ringtones (Feb-1998)	A feature that allows the user to load a new ringtone. This could be done by downloading the ringtone via a special SMS/MMS, or from the internet.
		Composer (Aug-1997)	It allows user to create the notes and then produce a customized ringtone.
		Recordable (Jan-2000)	This permits sound recording, e.g. someone’s voice, and then using it as a ringtone.
		Video Call (Mar-2003)	A 3G-network feature that allows two callers to talk to each other while at the same time viewing live video form each other's phone.
Connectivity	Protocols for exchanging data over short distances from fixed and mobile devices, creating personal area networks.	*Infrared* (Oct-1997)	A standard for transmitting data using an infrared port. It uses a beam of infrared light to transmit information and so requires direct line of sight and operates only at close range.
		Bluetooth (Aug-2001)	A wireless protocol for exchanging data over short distances from fixed and mobile devices, creating personal area networks.
		USB (Sept-2001)	A standard for a wired connection between two electronic devices, including a mobile phone and a desktop computer. The connection is made using a cable that has a connector at either end.
Messaging	In addition to pure voice calls, messaging has been a core service since the beginning of GSM mobile telephony.	*EMS* (Aug-1999)	An extension of SMS, which allowed mobile phone to send and receive messages that have special text formatting, animations, graphics, sound effects and ringtones. It is an intermediate technology between SMS and the rich multimedia messages (MMS).

		MMS (May-2002)	A store-and-forward messaging service that allows subscribers to exchange multimedia files as messages (text, picture, audio, video, or a combination). In order to send or receive a MMS, the user must have a compatible phone that is running over a GPRS or 3G network.
		SMS chat (Nov-2000)	Analogous to the pervasive use of SMS as a type of instant messaging much like chatting on a computer. The threaded message or conversation-style layout displays the incoming and outgoing messages between two participants in a single pane ordered chronologically.
		IM (May-2002)	The ability to engage in Instant Messaging services from a mobile handset. Mobile IM allows users to address messages to others using a dynamic address book full of users with their online status updated constantly. That permits anyone participating to know when their "buddies" are available for chat. Mobile IM is viewed as a logical extension of the popular SMS service.
		Email (Mar-1998)	Some phones provide a full email client that can connect to a public or private email server. There are different protocols used by the servers and some may not be supported by the phone's email client.
Display	Display is one of the most relevant aesthetical features of the mobile phone. Size, color and physical interaction have a strong influence on the user's experience.	*Colorscreen:* 4 colors (Sep-1997), 256 colors (Dec-2001), 4K color (Jun-2002), 65K colors (Nov-2002), 256K colors (May-2004),16MK color (Aug-2005)	The display is able to produce a number of different colors. A higher number results in a broader range of distinct colors. We have identified 6 levels of color screen:
		Display shape: Display Vertical (May-1998)*, Display Squared* (Nov-2000)	Mobile phone display has a shape that is convenient for the different function supported (Messaging, Photos, etc.). We identified two categories based on the display width/height ratio (Squared display, Vertical display).
		Touchscreen (May-1998)	A display that responds to direct touch manipulation, either by finger, stylus, or both.
Technological convergence	Technologies traditionally originating in other industries, and "converging" into the mobile phone one.	*Photocamera* (Aug-2002) *Videocamera* (Mar-2003)	Camera that can function as a digital camera, and in some cases can also shoot video.
		Photo resolution: 1Mp-2Mp (Oct-2004), 2Mp-3Mp (Jun-2005), 3Mp-4Mp (Sep-2006)	Indicates the number of pixels on a display or in a camera sensor (specifically in a digital image). A higher resolution means more pixels and more pixels provide the ability to display more visual information (resulting in greater clarity and more detail).
		Voice memo (Jan-1997)	Permits the users of devices that support them to record a note that can be heard whenever and wherever necessary. Some devices limit the duration of such memos whereas other allow recording until they run out of memory.
		MP3 (Dec-2000)	An audio storage protocol that stores music in a compressed format with very little loss in sound quality.MP3 files can be played using the music player of the mobile phone or set as a ringtone.
		Internet capabilities: HDML (Mar-1998); *WML* (Aug-1999); *HTML* (Mar-1998); *XHTML* (Nov-2002)	Various markup languages have been introduced to allow the handset to surf the internet. Most of them allow only the access to simplified internet pages.
		Document viewer (Jul-2005)	A program for displaying MS Word, Excel and PowerPoint files.
		FM-Radio (Apr-2000)	Permits the user to listen to most of the live-broadcasted FM radio stations. Almost all phones with FM radio tuner require a wired headset to be connected to the unit as it's used as an antenna.
		Games (Jan-1998)	Many phones include simple games for the user to pass the time. The games referred to here are ones preinstalled on the phone and do not require a wireless connection to play.

Source: definitions and technical descriptions of the sampled technologies were collected from both the special interest magazines used for the analysis, and online catalogues like www.gsmarena.com. Information on the month of introduction of a new technology in the UK market was collected from the special interest magazines used for our analysis.

FIGURE A1
Average number of innovations and imitations by UK mobile phone vendors (1997-2007)



Note: Values presented in the figure are based only on "regular phones"; smartphones are excluded. The average number of innovations (imitations) expresses, on average, in a given year, how many new product technologies are introduced (imitated) by handset vendors. The average number of technologies per product refers to the average number of technologies that handset vendors installed in their phones in a given year. The total number of technologies refers to the total number of different technologies that were adopted in a given year by handset vendors.

Biographical sketches

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